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Barium in Teeth as Indicator of Body Burden

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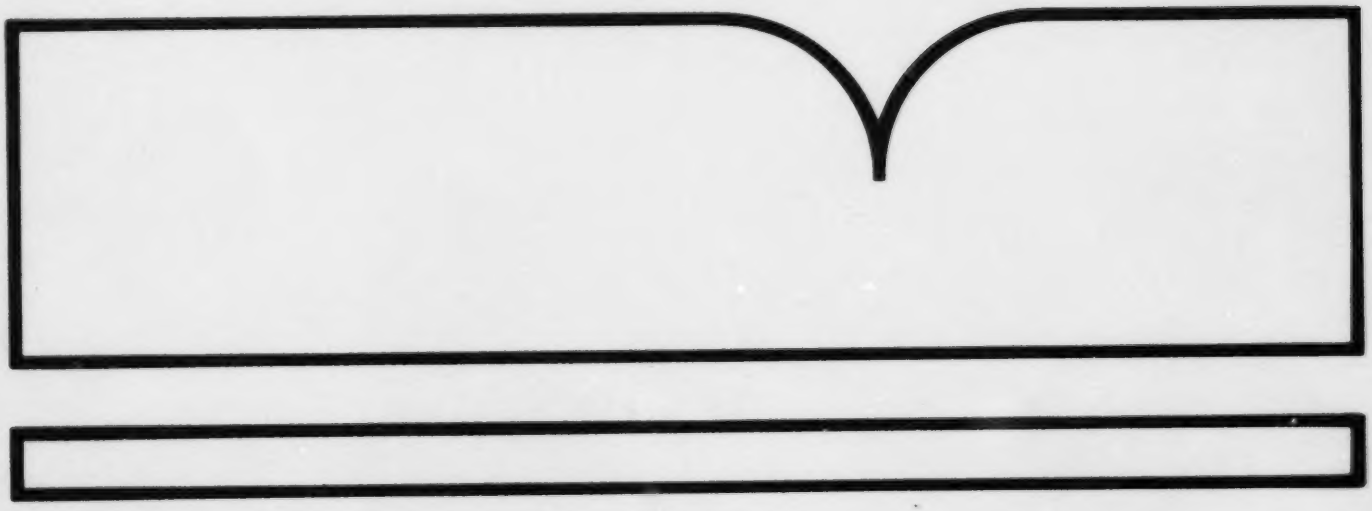

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CHAPTER XIX

BARIUM IN TEETH AS INDICATOR OF BODY BURDEN

Robert G. Miller,* John D.B. Featherstone,† Martin E.J. Curzon,† Tammy S. Mills,* and Carole P. Shields†

**U.S. Environmental Protection Agency,*
Health Effects Research Laboratory,
Toxicology and Microbiology Division,
Chemical and Statistical Support Branch,
Cincinnati, Ohio

†Eastman Dental Center,
Department of Oral Biology,
Rochester, New York

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ABSTRACT

A study was conducted to determine the biological availability of naturally occurring barium in a municipal drinking water by the analysis of barium in deciduous teeth of children. The grade school children of two Illinois towns were chosen for this study. The towns were chosen based upon the barium content of their drinking water supply, geographic proximity, population, ethnic composition, and socioeconomic status of its residents. The high barium town had an average drinking water level of 10 mg/L and a mean of 36 μg Ba/g Ca in teeth of life-long residents drinking city water compared to teeth levels of 7 μg Ba/g Ca in the children of the low level barium town which had a drinking water concentration of 0.2 mg/L barium.

INTRODUCTION

Barium (Ba), an alkaline earth element, occurs in the earth's crust at relatively high concentrations. However evidence thus far indicates that barium is not essential for life. Little is known of the biological function of barium in calcified or soft tissues even though it is found in the tissues of most living things. The most common geologic stratum containing barium is barite or $BaSo_4$, which is

the main source of the element for industrial use. The extensive industrial use of the element has meant that man is exposed to increasing concentrations of barium.

Municipal drinking waters in the USA contain barium ranging from 1.7–380 μg/L according to a report by Durfor et al. (1964). However, the average drinking water source accounts for only about 9% of average daily intake of barium which according to Schroeder et al. (1972) is approximately 1.0 mg/day. The bulk of barium intake is from food except where waters are particularly hard, containing barium at high concentrations.

The Safe Drinking Water Act of 1974 set a maximum contaminant level (MCL) for barium at 1 mg/L. It was suggested by Healy et al. (1963) that dietary differences in barium intake are reflected in contents of bone, enamel and dentin. Schroeder et al. (1972) indicated that clearance of barium in the urine of test subjects was only 9% and 5% of that of calcium and strontium respectively, indicating a preferential excretion of strontium. The absorption of barium compounds from the gut appeared to be poor both from water and food.

The oral toxicity of barium seems to depend upon the compound ingested. In a study of barium bioavailability, McCauley et al. (1983) found that in tubular fed rats the barium absorption rates were nearly identical with the use of barium chloride and barium sulfate, the carbonate was half as much for the first hour. Reeves (1979) reported that in rare instances of acute barium toxicity the mechanism of action of barium is based upon its physiological antagonism to potassium.

According to Kajola et al. (1979), symptoms following acute ingestion are vomiting, diarrhea, hypertension and hypokalemia. There have been no morbidity data presented that indicate any adverse health effects consistently associated with barium. Very few studies involving low dose barium ingestion have taken the absorbability of barium into account. Therefore this study was designed to determine whether or not the ingested barium via drinking water is absorbed.

Bauer et al. (1975) indicate that barium is a bone seeker and not retained by serum; therefore, assessment of body burden or intake can best be accomplished by analysis of calcified tissues such as bones and teeth. Since deciduous teeth were readily accessible, these were used as markers of barium exposure similar to Needleman et al. (1979) who used elevated dentine lead level as a marker for lead exposure. According to a report by Curzon et al. (1983), barium normally occurs in enamel of teeth at the 10–100 μg/gm levels.

Experimental Design. Through the review of the data reported by Brenniman et al. (1979), two communities were selected for this study based on levels of barium in the finished drinking water and the stability of this level over time, geographic proximity, population, ethnic composition and socioeconomic status.

West Dundee, Illinois was selected as the high barium community. The drinking water is obtained from one main well and contained 8.7–11.4 mg/L barium, and is aerated, fluoridated and chlorinated. In 1980 the total population of West Dundee was 3,551. In the selection of a control community where

the drinking water supply contained low levels of barium it was necessary to match a range of population size from 2,500 to 4,500 in order to prevent a size too small to obtain the required number of nonexposed teeth. The control communities were to be within 10–100 miles of West Dundee as a practical distance which would allow the control of tooth collection in both communities to be done by one person and far enough apart to eliminate the probability of substantial contamination of the control population.

Based on these dual criteria of size and location, twelve communities were initially selected.

West Dundee has a non-white population of (1.2%) which further dictated that the control community be predominantly composed of white residents. Two control communities were eliminated using this criterion.

The socio-economic status of residents of the remaining 10 prospective communities were compared to West Dundee by median family income and occupational categories.

After analysis of all available data taken from the 1980 census and based upon population, location, ethnic composition, and socio-economic status, the city of Marengo, Illinois was selected as the control community. Descriptive characteristics of the two communities are in Table 1.

Within both study communities, the target population was children in all elementary grades. Parental consent forms and questionnaires were collected from each participant. An agreement was made with the communities' public and parochial school systems to carry out the project.

Sample Collection. Exfoliated deciduous teeth were collected from the grade school children throughout the 1982–83 school year by a dental hygienist. As the teeth were collected, each tooth was placed inside a separate envelope, sealed, and the child's name, age, sex, and community residence written on the outside of the envelope. A record of each tooth was also maintained on the parental consent forms. The envelopes containing the teeth were sent to our laboratory where they were blind coded and sent forward to be analyzed for barium and calcium. Throughout the study, drinking water of each community was collected and preserved according to the EPA Handbook for Sampling and Sample Preservation of Water and Wastewater (1982) and analyzed for barium.

Analytical Methods and Quality Control. All identifiable teeth samples received were prepared for analysis by removal of root (if present) and treated with 2 ml of 10 percent (v/v) HCl for one week. For calcium analysis an aliquot

TABLE I.
Characteristics of the Two Study Communities

Community	Population	Miles Apart	Median Family Income	Percent Nonwhite
West Dundee	3551	25	22,996	1.2%
Marengo	4361	25	22,538	5.1%

(5 or 10 μl) of the dissolved enamel was diluted with 1200 ppm KCl solution to surpress ionization. Measurements were made by use of the flame atomic absorption spectrophotometry technique of Perkin–Elmer (1983) using nitrous oxide/acetylene fuel at a wavelength of 422.4 nm. The sensitivity for calcium is 0.05 mg/L for 1 percent absorption with a linear range up to 5 ppm with reproducibility of $\pm$ 1 percent. Each group of 10 samples was compared to a blank and a 2 ppm calcium standard analyzed before and after unknown analyses. Each reported measurement of calcium is a mean of ten analytical readings for that analysis. Recoveries for spiked solutions of calcium ranged from 95–105%.

Barium analyses were measured using flameless atomic absorption techniques of Perkin–Elmer (1983). Detection limit for each 20 μl aliquot of sample was 0.04 μg/L and linear to 200 μg/L. Each analysis was performed in duplicate with $\pm$ 5% reproducibility. Each set of 5 unknowns were compared to a blank and standards (4.0 μg/L) analyzed before and after each group. Recoveries for spiked solutions of barium ranged from 100–102%. Barium analysis of the community drinking water samples were performed by the flame atomic absorption spectrophotometry technique of Perkin–Elmer (1983).

Calculations. The ratio of the barium to calcium concentrations in the filtrate for each tooth was determined. This is a method of objectively determining the replacement of calcium in enamel with barium and also eliminates the impossible job of separating enamel (containing the barium) from dentin in primary teeth.

Upon completion of the analysis and submission of the data, the results of each sample were then identified as to town origin. Inspection of questionnaires showed that some samples were not from natives of either community. The final separation of the 291 teeth fell into 5 categories (A) West Dundee natives (N = 102), (B) West Dundee immigrants (N = 63), (C) Marengo natives (N = 112), (D) Marengo immigrants (N = 1), (E) Samples not analyzed because they were permanent teeth or had gross amalgam (N = 13). In addition to Categories D & E, 16 teeth from the other categories were not used in the statistical analysis because pertinent information (i.e., age, home water supply) was missing. There were 106 subjects whose teeth data (total teeth = 261) were used in the analysis.

The subjects contributed varying numbers of teeth during the course of the study, but in all residence categories 75–85% of the subjects contributed 3 or fewer teeth. For this reason, the range of the Ba/Ca ratio values for each subject was used to investigate the within subject variability. The median range for West Dundee subjects was twice that for the West Dundee non-natives and 4 times that for the Marengo residents. The values were 22.6, 13.4, and 5.6 respectively. Since the subjects contributed varying numbers of teeth, a summary measure was needed for each student as the response variable in the statistical analysis. There was no difference between the mean and median μg Ba/gm Ca ratios for a given individual. Thus, to investigate if an association existed with barium in drinking water, it was determined that the mean ratio was an adequate indicator of the subject's body burden of barium.

In addition to residence category and type of home water supply, age, sex and

TABLE II.
Concentrations of Barium, Calcium and Other Elements in the Drinking Waters of the Study Communities

Analysis Date	West Dundee (ppm)					Marengo (ppm)				
	Ca	Mg	Sr	F	Ba	Ca	Mg	Sr	F	Ba
Sept 1982	51.9	-	3.09	1.0	9.9	76.2	33.7	0.11	0.4	0.10
Nov 1982	55.1	20.1	2.20	0.5	11.4	74.8	33.4	0.12	0.4	0.50
Dec 1982	54.6	20.3	2.08	0.5	11.4	-	-	-	-	-
Feb 1983	-	-	-	-	9.0	-	-	-	-	0.10
May 1983	-	-	-	-	8.7	-	-	-	-	<0.10

length of residence in W. Dundee for non-natives were identified as potential confounders in the data analysis.

RESULTS

As an indicator of continued exposure to high and low levels of barium, Table II shows the stability of the Barium content of the studied communities' drinking water supplies (detection limit 0.10 mg/L).

The association of the concentration ratio of Ba/Ca in teeth with the potential confounders were considered individually in separate analysis. In Table III, comparisons were made of the Ba/Ca ratio between the sexes. In every residence category, the females had higher average ratios than the males. An analysis of variance for each residence category found no significant difference in the Ba/Ca ratio between the sexes in the West Dundee non-natives and the Marengo categories ($p > 0.30$), but a marginally significant difference was found in the West Dundee category ($p < 0.06$). The average ratio for females was 39.7 μg Ba/gm Ca compared to 22.6 for the males. Since the small number of males ($n = 5$) in the West Dundee non-native category and this borderline sex difference could possibly make differences in the Ba/Ca ratio between the residence categories, females and males were considered separately in a supplemental analysis.

A correlation between age and Ba/Ca ratio for each residence category showed no significant relationship (Table IV). Also, no significant relationship

TABLE III.
Comparison of Sex and Ba/Ca Ratio in the Residence Categories

Sex	Residence - Mean µg Ba/gm Ca Ratio					
	West Dundee	N	West Dundee Non-Native	N	Marengo	N
Female	39.7	19	14.5	16	7.7	19
Male	22.6	25	6.4	5	6.9	22

TABLE IV.

Comparison of Age and Ba/Ca Ratio in the Residence Categories

Age	Residence - Mean µg Ba/gm Ca Ratio					
	West Dundee	N	West Dundee Non-Native	N	Marengo	N
5	28.7	4	-	-	4.4	1
6	25.3	6	49.3	1	11.5	4
7	26.2	16	11.7	9	4.1	9
8	47.8	5	15.3	4	13.5	7
9	33.2	1	-	-	7.9	4
10	20.9	7	8.7	3	5.4	6
11	45.3	4	5.9	3	5.7	9
12	-	-	-	-	0.1	1
13	-	-	3.9	1	-	-
14	33.5	1	-	-	-	-
(p)	0.22	(>0.10)	-0.40	(>0.07)	-0.24	(>0.10)

was found between length of residence or age of immigration for non-natives of West Dundee and the Ba/Ca ratio. In Table V for each residence category, comparisons were made between the mean Ba/Ca ratio for each age and sex with no major differences indicated.

A two factor analysis of variance and Tukey's multiple comparison procedure were used to compare the Ba/Ca ratio among the 3 residence categories and between the 2 types of water supplies. A log transformation was used to stabilize the variance among the responses, a necessary condition for the statistical analysis. Table VI shows that the mean Ba/Ca ratio in the West Dundee residents was twice that of the non-native West Dundee residents and four times more than those living in the control community, Marengo ($p < 0.05$). The difference between the mean Ba/Ca ratios of the non-natives of West Dundee and the Marengo residents was not statistically significant ($p > 0.05$). In addition, because of the borderline significance between the sexes for West Dundee, females and males drinking city water were considered separately. For females, the same results as the overall analysis were found (West Dundee significantly higher than both Marengo and West Dundee nonnative). For males, the West Dundee residents were significantly higher than the Marengo residents, but not higher than the West Dundee nonnatives. The West Dundee residents drinking city water at home had a significantly higher Ba/Ca ratio than West Dundee residents drinking private well water at home ($p < 0.01$, Table VII). No significant difference among the residence categories was found when those drinking well water were considered separately.

TABLE V.
Comparison of Sexes Within Each Residence Category and Ba/Ca Ratio With Each Age Group

Age	Residence - Mean µg Ba/gm Ca Ratio											
	West Dundee				West Dundee Non-Native				Marengo			
	Female	N	Male	N	Female	N	Male	N	Female	N	Male	N
5	51.8	2	5.6	2	–	–	–	–	4.4	1	–	–
6	26.8	4	22.3	2	49.3	1	–	–	14.9	3	1.6	1
7	44.2	4	20.2	12	11.7	9	–	–	2.9	2	4.5	7
8	59.8	3	29.8	2	16.2	3	11.4	1	12.9	3	14.0	4
9	33.2	1	–	–	–	–	–	–	8.0	3	7.9	1
10	21.1	2	20.8	5	9.7	2	6.6	1	4.4	4	7.4	2
11	38.9	2	51.7	2	7.8	1	5.0	2	3.6	3	6.7	6
12	–	–	–	–	–	–	–	–	–	–	0.1	1
13	–	–	–	–	–	–	3.9	1	–	–	–	–
14	33.5	1	–	–	–	–	–	–	–	–	–	–

Although information was received through each child's questionnaire concerning the use of water softeners, a formal statistical evaluation of that data would be erroneous because of additional information needed (i.e., water softener on hot or cold or both water systems). However, by examining the means of the tooth enamel Ba/Ca ratio for the city water drinkers, the Ba/Ca ratio of West Dundee residents (N = 10) with water softeners was 32.0 µg Ba/g Ca or three times that of Marengo residents (N = 16) with water softeners at 10.6 µg Ba/g Ca.

TABLE VI.
The Ba/Ca Ratio of Deciduous Teeth Enamel in the Study Communities

Residence Category	N	µg Ba/gm Ca Ratio			
		Min	Med	Max	Mean
West Dundee	44	0.2	22.9	156.5	29.98
West Dundee (non-native)	21	1.9	8.65	49.3	12.56
Marengo	41	0.1	5.15	32.5	7.25

TABLE VII.
Comparisons of μg Ba/gm Ca Ratio of Deciduous Teeth Enamel of Residents Using Different Water Supplies

Water Supply	Residence					
	West Dundee		West Dundee Non-Native		Marengo	
	μg Ba/gm Ca	N	μg Ba/gm Ca	N	μg Ba/gm Ca	N
Well	10.79	10	7.47	3	6.42	6
City	35.62	34	13.41	18	7.39	35

CONCLUSION

Both male and female residents of West Dundee, the high barium exposure community, had significantly higher Ba/Ca ratios than those residents of the low barium exposure community. In addition, the West Dundee females had significantly higher Ba/Ca ratios than those of non-native West Dundee females. These differences were only seen in those subjects whose home water was supplied by the city.

The evidence from this study indicates that exposure to higher levels of barium via the drinking water source can result in a higher body burden of barium as measured in deciduous teeth. Because of the large variability of Ba/Ca ratios within a subject, a sampling of one tooth per child might not provide a reliable estimate of their body burden of barium. Further studies are needed to evaluate the differences between males and females and gather information on the critical exposure period.

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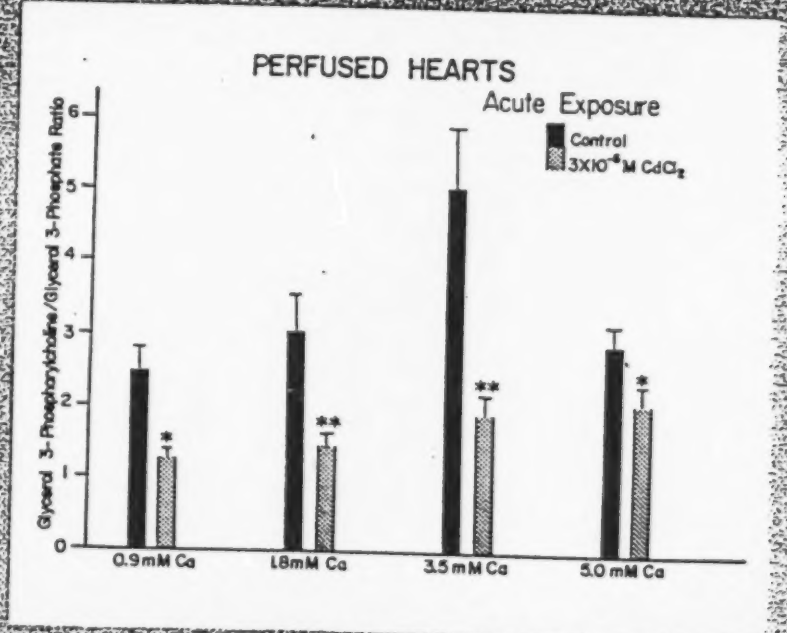

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